ON THE DESIGN OF HIGHER ORDER MODE ANTENNAS FOR LCLS II*

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Abstract

The upgrade of the Linac Coherent Light Source (LCLS-II) necessitates a major modification to the higher order mode (HOM) antenna of the conventional ILC elliptical 9-cell cavity. Due to the continuous wave nature of the proposed LCLS II Linac, the HOM antenna is required to bare higher RF losses. A modified design of the HOM antenna is presented in this paper ahead with a thorough thermal quench study in comparison with the conventional ILC design.

INTRODUCTION

Higher order modes (HOM) could be excited in the particle accelerator's superconducting cavities by the particle beam causing instabilities and affecting the particle accelerator performance. In this perspective it is essential to couple them away from the cavity through HOM antennas. However, the RF losses accumulated on the HOM antenna surface would induce heating and might cause the antenna surface to heat up and eventually quench if the temperature exceeded 9.2 K; the critical temperature for Niobium. The problem would even be rather more critical for continuous wave machines compared to pulsed machines.

LCLS II, a proposed coherent light source to be built at SLAC, is a continuous wave linear accelerator that would utilize state of the art superconducting cavities. HOM heating is one of the technical challenges that are facing this machine.

Given that we would like to utilize several existing ILC cavities in LCLS II project, we investigate in this paper, the possible shape modifications of the current ILC HOM antenna that could lower the RF losses (goal is reduce the losses by a factor of 5), while relatively preserving the current coupling (goal is to avoid reducing the coupling more than 10 times).

Figure 1 shows the geometry of the conventional ILC 9-cell elliptical cavity. The cavity has a power coupler and a HOM antenna (HOMc) on one side and a pick-up and a HOM antenna (HOMpu) on the other side. The front projection of the cavity is shown in Figure 2(a), depicting geometry of the HOM antennas and showing both the antennas and the f-parts. Figure 2(b) and (c) illustrate the nominal dimension of the HOM antenna and the gap size between the antenna and the f-part [1]. Possible modifications to the current ILC style of the HOM antenna are either in changing the gap size or changing the tip size.

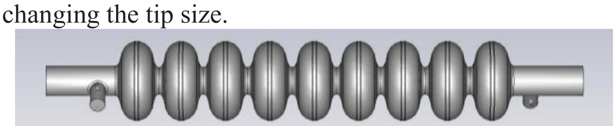

Figure 1: Geometry of the ILC Cavity.

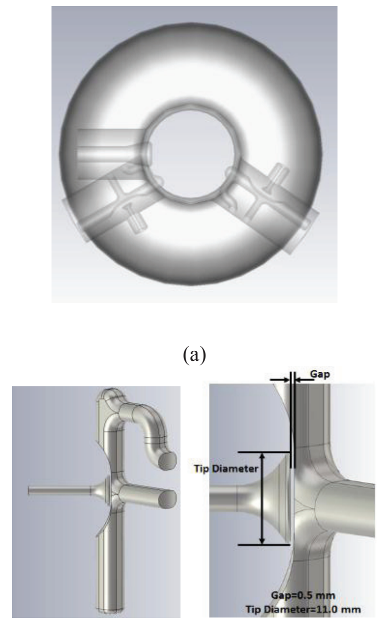

Figure 2: The geometry of the HOM coupler and antenna for the ILC cavity (a) Transparent front view of the cavity showing the HOM couplers (b) HOM antenna and f-part. (c) Dimension of HOM antenna.

ELECTROMAGNETIC ANALYSIS

In this section the electromagnetic performance of possible modified designs is reported. In this perspective, we will take the conventional ILC style antenna as a reference design and the modified versions will be evaluated based on their performance relative to this reference design as far as losses and external quality factor of the antenna. Ratios of both losses and Q_{ext} will be used as criteria of comparison.

a) Modified Design of Trimmed Antenna

Trimming the antenna should reduce the losses but will considerably change the coupling (i.e, Q_{ext}). To investigate this modification option, the geometry was simulated with a trimmed antenna. Two trimmed versions were simulated of 2.5 mm and 3.5 mm in gap size.

Figure 3(a) shows the effect of trimming the antenna on Q_{ext} for all higher order modes up to 2.5 GHz. A magnetic-magnetic (MM) boundary conditions were enforced on the pipe boundaries in all simulations. The ratio of Q_{ext} with respect to the ILC reference design (gap size=0.5 mm) is shown in Figure 3(b). Clearly, the gap size affects significantly the coupling. Ignoring the fundamental band around 1.3 GHz, the ratio of Q_{ext} is no less than 21.1, 7.4 for the trimmed version of 3.5 mm, and 2.5 mm in gap size, respectively.

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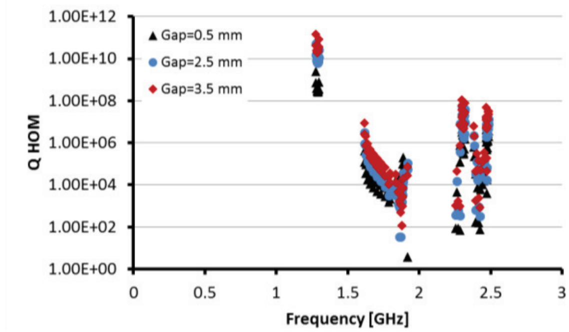
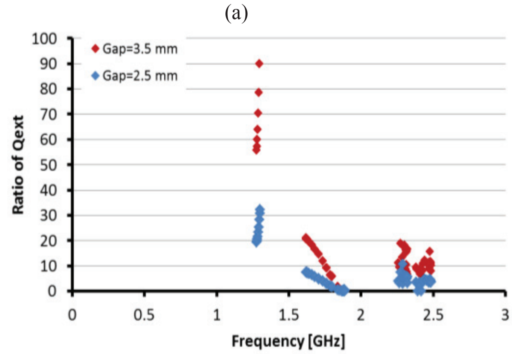


(a)



(b)

Figure 3: Effect of trimming the HOM antenna. (a) Q_{ext}. (b) Ratio of Q_{ext}.

Table 1 summarizes the results of the different trimmed versions indicating also the ratio of the RF losses. On average (between HOMc and HOMpu) the losses are projected to be reduced by a factor of 0.32, 0.21 for the trimmed version of 3.5 mm, and 2.5 mm in gap size, respectively.

Table 1. Effect of Trimming the HOM antenna.

Trim by	Gap [mm]	Ratio HOMc Losses	Ratio HOMpu Losses	Average Loss	Ratio of Q_{ext}
0.0 mm	0.50	1.00	1.00	1.00	1.00
2.0 mm	2.50	0.32	0.33	0.32	7.43
3.0 mm	3.50	0.21	0.21	0.21	21.06

Table 1 indicates that antennas with gap size larger than approximately 2.7 mm would have a ratio of Q_{ext} higher than 10.

b) Modified Version of Reduced Tip Size

The second option to modify the ILC antenna is to reduce the tip size while keeping the gap size as is, in order to relatively preserve the coupling. Figure 4 shows the geometry of the antenna and its tip after reduction.

In this section the effect of reducing the tip size on both the RF losses and the coupling is investigated. The tip size will be reduced from 11 mm diameter in case of the ILC to a pen like shapes (as shown in Figure 4) with tip size of 1.5 mm, 1.0 mm and 0.5 mm, respectively.

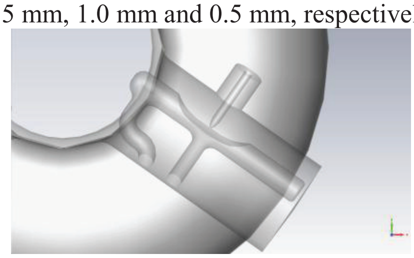
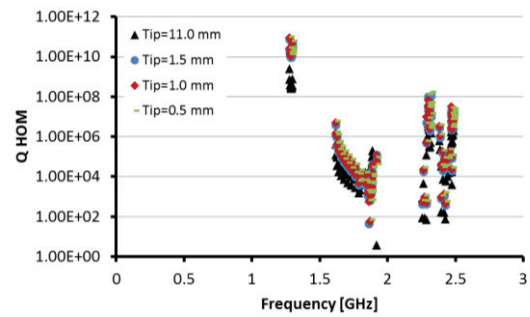


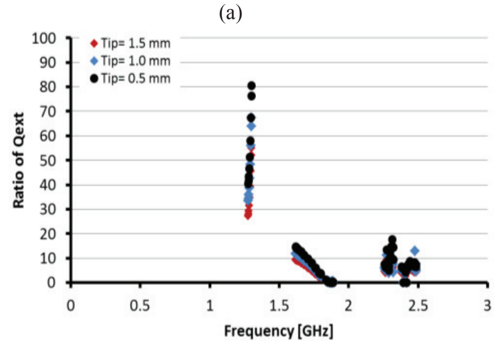
Figure 4: Reducing tip size of the HOM antenna.

Figure 5 (a) shows the effect of reducing the tip size on Q_{ext} for all higher order modes up to 2.5 GHz. Again magnetic-magnetic (MM) boundary conditions were enforced on the pipe boundaries in all simulations. The ratio of Q_{ext} with respect to the ILC reference design (tip size =11 mm) is shown in Figure 5(b). Clearly, the tip size affects noticeably the coupling. Ignoring the fundamental band around 1.3 GHz, the ratio is no less than 9.3, 11.6, and 14.3 for the tip size of 1.5 mm, 1.0 mm and 0.5 mm, respectively.

Table 2 summarizes the results of the different tip-sized versions indicating also the ratio of the RF losses (with respect to the ILC reference design). On average (between HOMc and HOMpu) the losses are projected to be reduced by a factor of 0.25, 0.24, and 0.23 for the tip size of 1.5 mm, 1.0 mm and 0.5 mm, respectively.



(a)



(b)

Figure 5: Effect of reducing the size of the HOM antenna. (a) Q_{ext}. (b) Ratio of Q_{ext}.

Table 2. Effect of reducing the tip size of the HOM antenna.

Tip Diameter [mm]	Gap [mm]	Ratio HOMc Losses	Ratio HOMpu Losses	Average Loss	Ratio of Q_{ext}
11	0.50	1.00	1.00	1.00	1.00
1.5	0.50	0.25	0.25	0.25	9.30
1.0	0.50	0.24	0.24	0.24	11.60
0.5	0.50	0.22	0.23	0.23	14.34

It is clear from Table 2 that antennas with tip size smaller than 1.5 mm in diameter, would have a ratio of Q higher than 10.

THERMAL ANALYSIS

We carried out a thorough thermal quench study of the proposed design in comparison with the conventional ILC design to fully examine the thermal properties of the structure in each case and demonstrate the potential of the modified structure.

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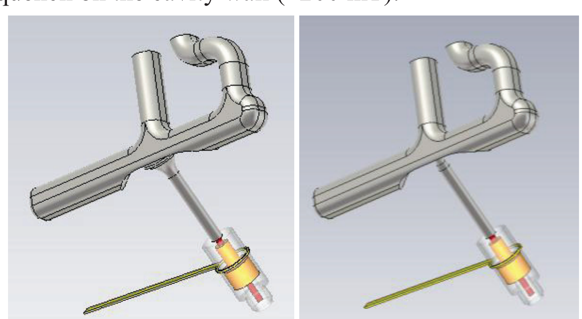
In order to run an accurate thermal analysis it was inevitable to represent the thermal conductivity of each material in the model as a function of temperature [2, 3]. Figure 6 shows the assembly model of both the ILC conventional antenna and the proposed modified version. The modified version is with pen-like antenna of 1.5 mm tip size and with 0.5 mm gap size. Dimensions were chosen based on the earlier electromagnetic analysis to secure both lower losses (RF losses are less by a factor of 4) and relatively preserve the coupling (Q_{ext} is higher by a factor of 9.3).
Figure 7 shows the temperature versus magnetic field for both the ILC geometry and the proposed modified version. In both geometries an Alumina ceramic, a Stainless Steel connector pin and Stainless Steel sleeve were assumed. Thermal quench analysis projects that the proposed modified design could handle up to 161 mT (~39 MV/m) compared to 58 mT (~ 14 MV/m), in case of the conventional ILC antenna. Meanwhile, the temperature profile of both geometries at quench field is shown in Figure 8.

Finally, the performance of both DESY [4] and JLAB [5] HOM antennas were also investigated, as shown in Fig. 7. Both antennas, having the material combination of Molybdenum pin, Copper socket, and Sapphire ceramic, perform very well, such that the cavity is not limited anymore by a quench on the HOM antenna but by the quench on the cavity wall (~200 mT).



(a) (b)

Figure 6: HOM antenna assembly, Niobium antenna and f-parts, Alumina ceramic, Stainless Steel pin, Stainless Steel sleeve, and the Copper cooling lead. (a) ILC style. (b) Modified ILC style.

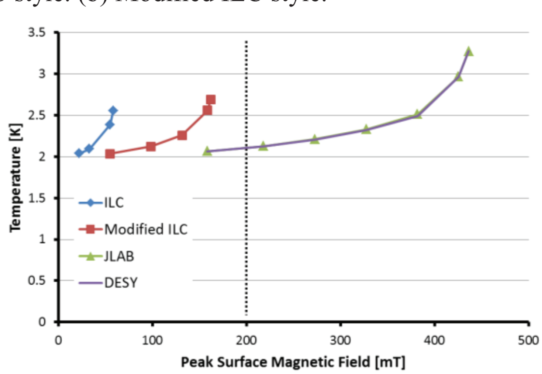
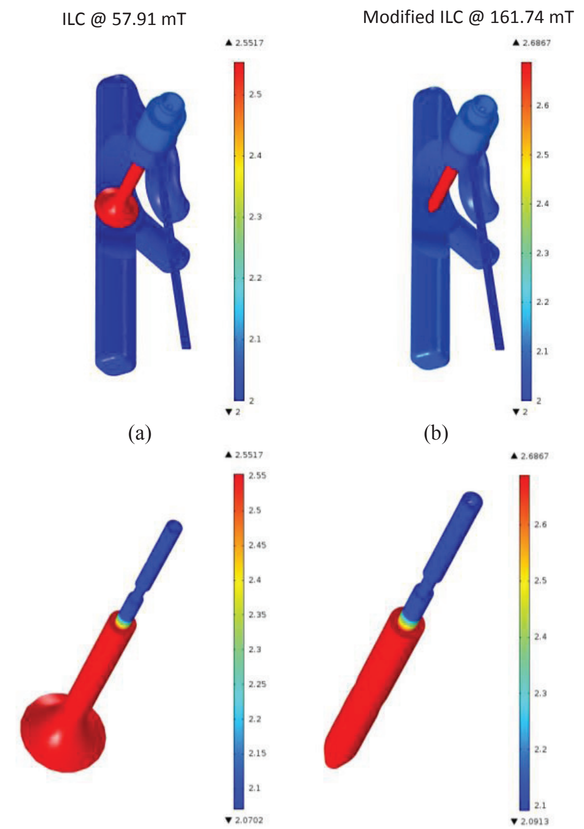


Figure 7: Antenna tip temperature versus peak magnetic field for the proposed modified antenna compared to ILC, JLAB and DESY designs.



(a) (b) (c) (d)

Figure 8: Thermal profile of both; the conventional ILC antenna and the modified one. (a) ILC antenna assembly. (b) Modified ILC antenna assembly. (c) ILC antenna. (d) Modified ILC antenna.

CONCLUSION

Electromagnetic analysis shows that the suggested design can sustain ~1/4 of the losses, while not increasing the external quality factor more than ~10 times. Meanwhile, thermal quench analysis projects that the proposed HOM antenna would handle up to 161 mT (~39 MV/m) compared to the conventional ILC antenna which handles only 58 mT (~ 14 MV/m).

The performance of the antenna could even be improved by changing the material of the ceramic to Sapphire, brazing antenna to the ceramic window, and making the sleeve all made from Copper, similar to what have been suggested by DESY for XFEL and JLAB for CEBAF.

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